White Paper

Intel® Energy-Efficient Performance

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Performance Made Energy Efficient Through New Technological Leaps

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Introduction

The drive for more performance is relentless, but is now matched with a need for greater energy efficiency—performance made energy efficient. Intel is addressing this need by delivering unprecedented innovations in processor architecture, silicon, platform technologies, and software. These innovations are delivering superior performance in the most efficient ways to give people what they care about most—whether it's smaller devices, increased performance, lower cooling bills, or better energy-efficiency.

Intel is bringing the benefits of energy-efficient performance to the world.

Energy-efficient performance is the intersection of great performance, expanded capabilities, and energy efficiency. The result: Performance made energy efficient. Extraordinary computer experiences across all segments.

Because Intel has recognized the growing need to balance ever-increasing performance gains with maximum energy efficiency, energy-efficient performance is now a key driver at Intel for the compute platform and the enablement of extraordinary computer experiences. These experiences include:

- Increased performance and improved multitasking for greater productivity
- Exciting new usage models and applications
- Greater power savings for enterprise computing
- Longer battery life for greater mobility
- Quieter desktops for homes and offices
- Thrilling game performance
- New form factors for the home, office, data center, and on the go

To provide the energy-efficient performance these experiences require, Intel is making a total commitment to advancing energy-efficient performance in all computing segments.

Introducing Intel® Core™ Microarchitecture

The need for energy-efficient performance is not new. In fact, in the early 2000s Intel introduced the first mobile-optimized microarchitecture and platform. Today, Intel is expanding many of the key energy-efficient, performance-optimized features of this mobile microarchitecture across all its platform segments through the recent introduction of Intel® Core™ microarchitecture. Intel Core microarchitecture delivers superior performance through several key new innovations and extends the power–saving philosophy first delivered in the Intel® Pentium® M processor microarchitecture. Products based on this architecture meet the requirements of the mobile segment and the needs for greater compute density, performance, and energy efficiency across other key sectors (desktop, workstation, and mainstream server).

Intel is in the process of transitioning the majority of its volume products to Intel Core microarchitecture-based multi-core processors. These products include Intel® Core™2 Duo processors for desktop PCs, Intel Core 2 Duo mobile processors for laptops, and the Dual-Core Intel® Xeon® processor 5100 series for dual-processor servers. Intel is now solidly in the lead in performance and energy efficiency in most of these product segments.

According to benchmark tests:

- **The Dual-Core Intel Xeon processor 5100 series** delivers up to 135 percent performance improvements[1] and up to a 40 percent reduction[2] in energy consumption over previous Intel server products.
- **The Intel Core 2 Duo processor for the desktop** delivers up to 40 percent improvement in performance and up to 40 percent reduction in power as compared to today's high- end Intel® Pentium® D processor 960.[3]
- **The Intel Core 2 Duo mobile processor** delivers more than twice the CPU performance[4] and up to 28 percent power reduction[5] with the new Intel® Centrino® Duo mobile technology laptops based on the Intel Core 2 Duo processor as compared to previous generation Intel® Centrino® mobile technology-based laptops.

Intel produces the best energy-efficient performance CPU transistors in volume in the world when compared to published results of CPU competitors.

- Our Second Generation Strained Silicon Technology increases transistor performance by 10 to 15 percent without increasing leakage.
- Overall compared to 90 nm transistor technology, our enhanced energy-efficient performance 65 nm transistors provide:
  - Over 20% improvement in transistor switching speed or greater than five times reduction in leakage power
  - Over 30% reduction in transistor switching power
- We were first to announce 45 nm process technology with a fully functional 153 Mb SRAM demonstration in January 2006, and we are on track to deliver products based on 45 nm in 2007.

Industry-Leading Silicon Process Technology

Intel's 65-nanometer (nm) silicon process technology increases both performance and energy efficiency compared to previous-generation 90 nm technology (see sidebar). Combined with our unparalleled manufacturing capacity, our industry-leading 65 nm process CPU transistors provide a solid production base for the new Intel Core microarchitecture. Currently Intel is at least one year ahead of the industry in process technology and has three 65 nm fabs in production—D1D in Oregon, Fab 12 in Arizona, and Fab 24 in Ireland. To illustrate the speed of the transition to 65 nm manufacturing, as of second quarter 2006, more of Intel's chips were being manufactured on 65 nm than on 90 nm. By accelerating delivery of Intel Core microarchitecture-based products, Intel is bringing these new levels of energy-efficient performance to more people faster.

Rewriting the Rules with a New Cadence for Technological Advancement

Building on the foundation of Intel Core microarchitecture, Intel is on a fast-paced trajectory to deliver products with superior performance and energy-efficiency for years to come. We recently announced[6] a new cadence in the microarchitecture arena. Intel plans to deliver a new, optimized energy-efficient performance microarchitecture approximately every two years that supports all process technology advancements. The consequences of this new cadence in combination with Moore's Law will be groundbreaking. People will see continuous improvements in performance, power savings and constant flow of new computing capabilities year after year (Figure 1).

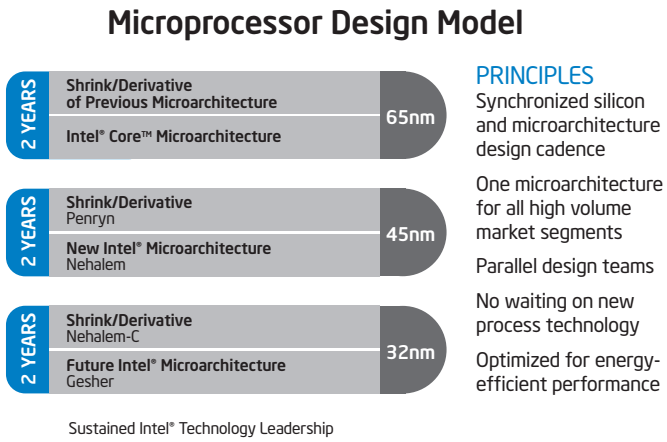


Figure 1. Intel is using a multipronged approach with design teams all over the world working in parallel to develop new microarchitectures about every two years that will take advantage of Intel's latest process technology advancements .

This new approach combining process technology advancements and microarchitecture advancements in two-year cycles is the starting point for a new computing revolution that could bring even more dramatic change than what we've seen over the past two decades of Intel driving Moore's law. Intel is on pace to enable another tenfold improvement in energy-efficient performance within the next 10 years—an achievement that will further increase computing responsiveness and reduce worldwide power consumption for computing devices. Intel has design teams in the United States, Israel, China, Russia, and India developing new microarchitectures in parallel. By late 2007 Intel process technology will begin the transition from 65 nm to 45 nm and effectively double the number of transistors in a given die size. Intel will use these transistors to add more cache and features to reach yet another level of unprecedented energy-efficient performance. In 2008 Intel expects to ship a new microarchitecture code-named "Nehalem." Initial products based on Nehalem microarchitecture will use 45 nm process and are expected to deliver several percentage-point improvements in per-

formance and energy-efficiency, as well as add new and innovative capabilities. This cycle will continue to 32 nm and another new microarchitecture targeted for 2010.

Next Major Milestone: Expanding the Capabilities of Intel® Architecture

Building on the energy-efficient performance foundations of our microarchitecture, Intel is expanding the capabilities of Intel® 64 Instruction Set Architecture with several new instructions that will provide building blocks for delivering expanded capabilities, enhanced performance, and greater energy-efficiency to all Intel® 64 architecture-based microprocessors. These new instructions are the next major milestone in our process and microarchitecture cadence.

The new instructions will enable Intel microprocessors across all market segments to deliver superior performance and energy efficiency to a broad range of 32-bit and 64-bit applications effectively incorporating these instructions. Applications that will benefit include those involving graphics, video encoding and processing, 3-D imaging, gaming, Web servers, and application servers. The instructions will also benefit high-performance applications like data mining; databases; complex searching and pattern-matching algorithms; audio, video, image and data compression algorithms; parsing and state machine-based algorithms; and many more. These instructions are expected to be available in Intel microprocessors starting with Penryn. For more information, please see www.intel.com/technology/architecture/new_instructions.htm

Intel® Core™ Microarchitecture Innovations

Intel Core microarchitecture includes these groundbreaking advancements:

- **Intel® Wide Dynamic Execution**—An advancement enabling delivery of more instructions per clock cycle. Every execution core is 33 percent wider than previous generations, allowing each core to fetch, dispatch, execute, and retire up to four full instructions simultaneously. Further efficiencies are achieved through more accurate branch prediction, deeper instruction buffers for greater execution flexibility, and additional features to reduce execution time.
- **Intel® Intelligent Power Capability**—A power management strategy designed to reduce power consumption and design requirements. This feature manages the runtime power consumption of all the processor's execution cores. It includes an advanced power gating capability that allows for an ultra fine-grained logic control that turns on individual processor logic subsystems only if and when they are needed.
- **Intel® Advanced Smart Cache**—This multi-core optimized cache significantly reduces latency to frequently used data. It improves performance and efficiency by increasing the probability that each execution core can access data from a higher performance, more efficient cache subsystem that uses shared L2 cache.
- **Intel® Smart Memory Access**—This memory access innovation enhances system performance by optimizing the use of available data bandwidth from the memory subsystem and hiding the latency of memory accesses. Intel Smart Memory Access includes an important new capability called "memory disambiguation." This feature increases the efficiency of out-of-order processing by providing the execution cores with the built-in intelligence to speculatively load data for instructions that are about to execute before all previous store instructions are executed.
- **Intel® Advanced Digital Media Boost**—This advancement significantly improves performance when executing Streaming SIMD Extension (SSE) instructions. It accelerates a broad range of applications, including video, speech and image, photo processing, encryption, financial, engineering, and scientific applications. Intel Advanced Digital Media Boost enables 128-bit instructions to be completely executed at a throughput rate of one per clock cycle, effectively doubling, on a per clock basis, the speed of execution for these instructions as compared to previous generations.

On the Path to Quad Core and Beyond

What makes the drive for energy-efficient performance so important now is what's to come in the future. The number of cores on a chip will continue to multiply from four to eight and beyond in coming years, launching an era of vastly more powerful computers. With this in mind, Intel researchers are already working toward a new era we call "tera-scale" computing, where energy efficiency is an important design consideration for delivering teraflops of computing power and handling terabytes of data.

Tera-scale research is vital for finding ways to process and interpret the world's growing mountains of data. Business and government data stores are becoming larger and more complex by the year. Medical petscan machines already generate images in excess of half a terabyte. Even at home, consumers are becoming digital pack rats, accumulating hundreds of hours of video, thousands of documents, and tens of thousands of digital photos. To effectively manage and use this data, future architectures will need to scale to tens or even hundreds of cores working in parallel. Some cores may be dedicated to special purposes or workloads such as graphics rendering. At Intel, research is underway on how to define scalable, power–aware architectures that will combine these cores and manage the data and processes amongst them. In the tera-scale era, scalable multi-core architectures will be central to improving performance, managing energy use, and adding features that bring new capabilities. For more details please refer to www.intel.com/technology/techresearch/terascale.

Delivering Energy-Efficient Performance through Expanded Platform Capabilities

One way Intel efficiently delivers new and advanced capabilities to end users is by including advanced technologies directly in the microprocessor, platform silicon, and/or software. These technologies add features that enhance energy efficiency, security, multitasking, virtualization, mobility, manageability, reliability, flexibility, performance, and more. Examples include Intel® Virtualization Technology, Intel® Active Management Technology, Intel® I/O Acceleration Technology, and Demand-Based Switching.

For additional platform-level power savings, Intel works closely with the industry and academia. Recent achievements include: advanced heat sync technologies, higher efficiency power supplies, enhanced halt state, and thermally advantaged chassis. We also work on power management tools—like Pconfig and Power Supply Management Interface (PSMI), Enterprise Power and Thermal Manager (EPTM), and Intel® Power Tools—plus research on new battery technologies, power-efficient LCD displays for laptops, and link power management. For a detailed discussion on Intel's efforts in these areas, please download the white paper, Energy-efficient Platforms at ftp://download.intel.com/technology/eep/green-paper.pdf.

Intel delivers these capabilities through a variety of platforms, including Intel Centrino mobile technology, Intel® Viiv™ technology, Intel® vPro™ technology, and our server platforms. (For more on our advanced platform technologies, see www.intel.com/platforms/technologies.htm.)

Enabling Energy-efficient Performance through Intel® Software

Software is a key ingredient in realizing the benefits of energy-efficient performance. For years Intel has educated software developers on how to make applications power-friendly and provided power-monitoring and analysis tools to help identify and correct power-wasting code. Software is even more important with multi-core platforms. The throughput, energy efficiency, and multitasking performance of these platforms are all more fully realized when application code is threaded and multi-core ready. Intel provides extensive programs with software developers, software development products, and collaborations to accelerate the delivery of Intel Core microarchitecture's energy-efficient platform benefits.

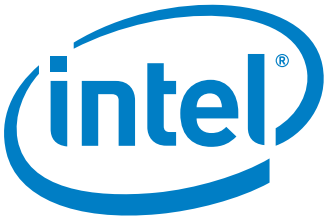
- Intel® Software Development Products —These products and tools embrace multi-core programming best practices, facilitate threading applications, and help developers shorten time to market. Products include Intel® Compilers, Intel® Performance Libraries, Intel® VTune™ Performance Analyzers, Intel® Thread Checker, Intel® Thread Profiler, Intel® Cluster Tools, and Intel® Threading Building Blocks. Intel also offers software platform products and technologies such as Intel® Platform Administration Technology, Intel® Innovation Framework for EFI, and Intel® Media Codecs to help speed value delivery in the platforms.
- Software Programs and Services — Beyond software products, Intel works with leading software vendors to provide tools, resources, expertise, and relationships to drive thread optimization across a wide range of applications. Through deep technical onsite collaborations with operating system (OS), firmware, and database vendors, we enable them to fully utilize the multi-core platforms prior to launch. Intel also works with industry groups like ODSL and Eclipse to shape the direction of the open source community. In addition, Intel works with thousands of independent software vendors (ISVs) to help them prepare and optimize their solutions for new platform technologies including the multi-core platforms. Intel software programs and services include the Intel® Early Access Program, Intel Competency Centers, Intel® Software College, Intel® Software Network, Intel® Solution Services, and Intel Capital.

Investing in the Future— Our Continuing Commitment

To meet future requirements, Intel invests extensively in in-house research and development, as well as industry and academic collaboration. Through Intel Capital, Intel also supports promising enterprises driving Internet growth, enabling new usage models, and advancing industry standards. In 2005, Intel spent $5.1 billion on research and development alone, spurring new advancements and innovation. Our commitment and investments span the range of computing and communications technologies, targeting improvements at work and at home. Our unique commitment to research and development includes a worldwide network of researchers, scientists, and engineers (more than 7,000 technologists and thought leaders) who are continually pioneering new technologies to deliver compelling new computing experiences.

Summary

Through energy-efficient performance advances across our microarchitecture, silicon, platforms, and software, Intel is on the fast path to creating computers in all sectors and form factors that reach ever greater milestones in performance, energy-efficiency, and expanded capabilities. From high-performance servers with tens of cores that will allocate processor resources for energy efficiency, to wireless tablet computers that through voice recognition enable a physician to update patient records for an entire day between charges, to home platforms running immersive games that envelop you in 3-D experiences that react to your body movements, Intel's vision of energy-efficient performance will enable more compelling, extraordinary computer experiences for years to come. Intel Core microarchitecture-based processors and our 45 nm process technology coming in 2007 are but two of the many more advances—and marvels—coming your way.



www.intel.com

1. 135 percent Performance Claim based on published results on SPECjbb2005* benchmark as of June 26, 2006. Configuration details:

   Dual-Core Intel® Xeon® Processor 2.80 GHz based platform details: Fujitsu Siemens* Computers PRIMERGY RX300 S2 server platform: Two Dual-Core Intel Xeon processors 2.80 GHz with 2x2 MB L2 cache 800 MHz system bus, 4 GB DDR2, Microsoft Windows Server 2003* Java HotSpot* Server VM (build 1.5.0_06-b05). Referenced as published at 41986 bops and 41986 bops/jvm. For more information see www.spec.org/jbb2005/results

   Dual-Core Intel® Xeon® Processor 5160 based platform details: Fujitsu Siemens BX620 S3* Server platform with two Dual-Core Intel Xeon Processor 5160, 3.00 GHz with 4 M L2 Cache, 1333 MHz system bus, 8 GB (8 x 1 GB) FB-DIMM memory, Windows 2003 Enterprise Edition* BEA JRockit(R) 5.0 P26.4.0. Referenced as published at 100407 bops and 100407 bops/jvm. For more information see www.spec.org/jbb2005/results

2. 40 percent reduction based on Processor TDP comparison between previous generation Dual-Core Intel® Xeon® Processor 2.80 GHz and new Dual-Core Intel® Xeon® Processor 5160.

3. Performance based on SPECint_rate_base2000* (2 copies) and energy efficiency based on Thermal Design Power (TDP), comparing Intel® Core™2 Duo E6700 to Intel® Pentium® D Processor 960. Actual performance may vary. See www.intel.com/performance for more information.

4. As measured by SPEC CPU2000* (SPECfp*_rate_base2000 and SPECint_rate_base2000*) comparing Intel® Pentium® M Processor 780 and 750 with Intel® Core™2 Duo Processor T7600 and T5600. Actual performance may vary. See www.intel.com/performance/mobile/benchmarks.htm for important additional information. SPEC, SPECint, SPECfp, SPECrate, SPECweb, SPECjbb are trademarks of the Standard Performance Evaluation Corporation. See: http://www.spec.org for more information on the benchmarks.

5. Based on power utilization measured by average power of Intel components of a pre-production Intel® Core™2 Duo processor-based laptop as compared to an Intel® Pentium® M Processor-based notebook. Actual performance may vary. See www.intel.com/technology/eep/platforms.htm for important additional information.

6. Intel CEO Paul Otellini in Spring 2006 Financial Analyst Forum.

Printed in the United States. 0906/RMR/HBD/PDF 315258-001US

Links

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References

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